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Characteristics and sources of the electron density irregularities in the mid-latitude E and F regions

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"Characteristics and sources of the electron density irregularities in the mid-latitude *E* and *F* regions"

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Abstract:

A new 40.8 MHz coherent scatter radar was built in Daejeon, South Korea (36.18ºN, 127.14ºE, dip latitude: 26.7ºN) on 29 December 2009, and has since been monitoring the occurrence of field-aligned irregularities (FAIs) in the northern middle latitudes. We investigated the characteristics and occurrence climatology of the FAIs in the middle latitude *E*- and *F*-region ionosphere using the Daejeon VHF radar data. Depending on the manner of occurrence of the backscatter echoes, the *E*-region echoes are largely divided into two types: quasi-periodic (QP) and continuous echoes. The QP-type echoes occur more frequently than the continuous-type echoes do and the echo intensity of the QP type is stronger than that of the continuous type. It is found that *E*-region irregularities occur maximum in summer during both nighttime and daytime and they are mainly observed in the post-sunset and post-sunrise periods. The *F*-region FAIs in the mid-latitude are bounded to occur during the nighttime between local sunset and sunrise [*J. Astron. Space Sci.*, *31(1)*, 15-23, 2014].

The *F*-region FAIs preferentially occur around 250–350 km at 18:00–21:00 local time (post-sunset FAI), around 350–450 km near midnight (nighttime FAI), around 250–350 km before sunrise (pre-sunrise FAI), and around 160–300 km after 05:00 local time (post-sunrise FAI). The occurrence rates of nighttime and pre-sunrise FAIs are maximal during summer, though the occurrence rates of post-sunset and post-sunrise FAIs are maximal during the equinoxes. FAIs rarely occur during local winter. The occurrence rate of *F*-region FAIs increases in concert with increases in solar activity. Medium-scale traveling ionospheric disturbances (MSTIDs) are known as an important source of the *F*-region FAIs in middle latitudes. The high occurrence rate of the nighttime FAIs in local summer is consistent with the high occurrence rate of MSTIDs in that season. However, the dependence of the FAI activity on the solar cycle is inconsistent with the MSTID activity. The source of the *F*-region FAIs in middle latitudes is an open question. Our report of different types of FAIs and their occurrence climatology may provide a useful reference for the identification of the source of the middle-latitude FAIs [*J. Geophys. Res.*, *120*, 10,107–10,115, 2015].

We present, for the first time, the statistical characteristics of the mid-latitude afternoon *E*-region FAIs based on the continuous and long-term Daejeon radar observations. Echo signal-to-noise (SNR) of the afternoon *E*-region FAIs is found to be as high as 35 dB, mostly occurring around 100-135 km altitudes. Most spectral widths of the afternoon echoes are close to zero indicating that the irregularities during the afternoon time are not related to turbulent plasma motions. It is observed that the occurrence of the afternoon *E*-region FAIs has strong seasonal variations with maximal occurrence in summer and minimal occurrence in winter season. And, we investigate the afternoon *E*-region FAIs - Sporadic *E* (E_s) relationship. It is shown that the virtual height of E_s ($h'E_s$) falls mostly in the height range of 105-110 km and these heights are 5-10 km greater than the FAI bottom side. No relation is found between FAIs SNR and top frequency (f_tE_s) (or blanketing frequency (f_bE_s)). SNR of FAIs, however, is found to be related well with (f_tE_s - f_bE_s). [submitted to *ASR*].

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14. ABSTRACT
Research team has reported the study of electron density irregularities in the ionosphere that lead to the diffraction of radio waves, which can be responsible for scintillation, fading, and the disruption of propagating signals. Significant efforts have been made to establish information on the occurrence climatology of such irregularities, to understand the onset conditions of such irregularities, and to predict or avoid the impact of these irregularities on society.

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Introduction:

Electron density irregularities in the ionosphere lead to the diffraction of radio waves, which can be responsible for scintillation, fading, and the disruption of propagating signals. Significant efforts have been made to establish information on the occurrence climatology of such irregularities, to understand the onset conditions of such irregularities, and to predict or avoid the impact of these irregularities on society. Such electron density irregularities in the ionosphere exhibit an anisotropic distribution with respect to Earth's magnetic field owing to the elongated nature of the irregularities along the field lines. For this reason, the ionospheric electron density irregularities are often referred to as field-aligned irregularities (hereafter abbreviated simply as "(FAIs)").

Extensive studies of *E*-region FAIs have been made in the equatorial [e.g., *Fejer and Kelley*, 1980], low-latitude [e.g., *Patra and Rao*, 1999] and auroral regions [e.g., *Haldoupis*, 1989] with radars and in situ measurements. In middle latitudes, investigation of *E*-region FAIs was started with the observation of sporadic *E* (*Es*) at an altitude of ~105 km with a portable 50-MHz Doppler radar on the island of Guadeloupe in French West Indies near Arecibo, Puerto Rico [*Ecklund et al*., 1981]. In the last two decades, intensive efforts have been made in both observation and theory to better understand *E*-region FAIs at middle latitudes using the 46.5 MHz Middle and Upper atmosphere (MU) radar at Shigaraki (34.89°N, 136.10°E, 25.7°N dip latitude) in Japan [e.g., *Fukao et al.*, 1991]. Investigations using observations from the MU radar have revealed the important features and characteristics of mid-latitude *E*-region FAIs. From MU radar observations, *Yamamoto et al*. [1991] first recognized two types of radar echoes in the middle-latitude *E* region: "quasi-periodic (QP)" echoes appearing intermittently at altitudes above 100 km with periods of 5-20 min from post-sunset time to midnight and "continuous" echoes appearing continuously at altitudes of 90-100 km mainly during the post-sunrise period. A number of efforts have been carried out to investigate the generation mechanism of the post-sunset QP echoes in middle latitude. The generation mechanism of the QP echoes was proposed by *Woodman et al*. [1991]. They pointed out that atmospheric gravity waves could modulate *Es* layers to keep the plasma unstable and could explain the quasi-periodicity. *Tsunoda et al*. [1994] modified the theory of *Woodman et al*. [1991] and suggested a polarization electric field that originates from a spatial modulation of an *Es* layer due to a gravity wave. The SEEK (Sporadic-*E* Experiment over Kyushu) [e.g., *Fukao et al*., 1998; *Tsunoda et al*., 1998; *Yamamoto et al*., 1998] and SEEK-2 (Sporadic-*E* Experiment over Kyushu-2) [e.g., *Saito et al*., 2005; *Yamamoto et al*., 2005] were conducted in order to reveal the generation mechanism of QP echoes in the mid-latitude *Es* layers. From both campaign, it was found that polarization electric fields were induced from the *Es* layer with QP echoes, mapped upward along the geomagnetic field, and played an important role in determining the structures of the whole ionospheric *E* region. *Otsuka et al*. [2007] reported that the electric fields associated with the *F* region medium-scale traveling ionospheric disturbances (MSTIDs) could be closely coupled to those associated with QP echoes in the *E* region, from simultaneous observations of VHF radar backscatter from FAI in the *E* region and MSTIDs in 630-nm airglow images.

The study of *F*-region FAIs in the middle latitudes has been conducted using the observations of the MU radar [*Fukao et al.*, 1985a, b]. The MU radar observations have been used to investigate the FAI structure, and to compare with other observations. In the MU radar observations reported by *Fukao et al.* [1991], the FAIs appeared as patches and extended vertically in the altitude range of 220 and 500 km. Strong backscatter echoes were observed in the patches that displayed positive Doppler velocity. *Fukao et al.* [1991] investigated the local time (LT) distribution of the *F*-region FAIs using the MU radar data acquired during 6–17 June 1987. Their results showed the occurrence of the FAIs between 21:15 and 04:30 LT. The emergence (21:15 LT) and cease (04:30 LT) times of the FAIs were close to the sunset time of the local *F* region and sunrise time of the local *E* region, respectively. The occurrence rate of the FAIs maintained about 50% at 22:15–04:00 LT. *Fukao et al.* [1991] briefly described the decreasing tendency of the occurrence rate of the *F*-region FAIs with an increase in solar activity, as well as a more frequent occurrence of FAIs near the June solstices as compared with other seasons; however, their study was not extended to the quantitative investigation of the occurrence climatology.

As mentioned above, our understanding of the middle latitude *E*- and *F*-region irregularities was enriched by the observations of the MU radar. Because of limitation for the number of observations of such irregularities due to operation on a campaign basis, however, the observations of *E*- and *F*-region FAIs from MU radar as far have only been reported episodically without any particular occurrence statistics and are not sufficient for the investigation of the occurrence climatology, consistency and recurrence of middle-latitude FAIs, which require long-term observational data. A very high frequency (VHF) coherent scatter radar was built in Daejeon, South Korea (36.18°N, 127.14°E, 26.7°N dip latitude) on 29 December 2009 in order to continuously monitor the electron density irregularities in the *E* and *F* regions in the northern middle latitudes. We investigate the characteristics and occurrence climatology of the FAIs in the middle latitude *E*- and *F*-region ionosphere using the continuous and long-term Daejeon radar observation data. Meanwhile, no the afternoon (i.e., from noon to sunset time) *E*-region FAIs in middle latitude have been reported yet. Therefore, for the first time, we report the afternoon observations of the mid-latitude *E*-region FAIs made by the Daejeon radar. We present the statistical characteristics of the mid-latitude afternoon *E*-region FAIs based on the continuous and long-term radar observations. And, to investigate the afternoon *E*-region FAIs - E_s relationship, the FAIs have been also compared with *Es* parameters based on observations made from an ionosonde located at Icheon (37.14°N, 127.54°E, 27.7°N dip latitude), which is 100 km north of Daejeon.

Experiment:

A VHF coherent scattering radar was built at Daejeon (36.18°N, 127.14°E, 26.7°N dip latitude) in South Korea aiming at continuous monitoring of middle-latitude FAIs in the Far East Asian sector. The Daejeon VHF radar is operated at a frequency of 40.8 MHz and with a peak transmitting power of 24 kW. The basic parameters and the technical specifications of the radar are listed in Table 1. The antenna system, occupying an area of 85 m × 40 m, is a phased array of 12 × 2 five-element Yagi antennas. To detect the coherent backscatter from the *E*- and *F*-region irregularities, the radar beam is oriented at a 48° zenith angle due magnetic north, which satisfies the field perpendicularity condition at the *E*- and *F*-region heights. Half-power full beam widths in azimuth and zenith directions are 10° and 22°, respectively. Except for some limited periods, the radar has been in continuous operation since 29 December 2009. The signal-to-noise ratio (SNR), Doppler velocity, and spectral width data in the *E* and *F* regions are recorded every minute. Table 2 lists the observational mode for the *E*- and *F*-region FAIs. The inter-pulse period (IPP) for the *E*- and *F*-region experiments are 2.5 and 6.6 ms, respectively, and the pulse widths are 6 and 32 μs, respectively. The range resolutions of the VHF radar measurements for the *E* and *F* regions are 900 m and 4.8 km, respectively. The FAIs detected by the 40.8 MHz radar correspond to a scale size of 3.68 m (half wavelength of the transmitted pulse).

Table 1. Specifications of the VHF ionospheric radar at Daejeon.

Parameter	Value
Latitude	36.2ºN
Longitude	127.1ºE
Magnetic latitude	26.7ºN
Antenna	12×2 array of 5-element Yagi antennas
Frequency	40.8 MHz
Peak power	24 kW
Band width	170 kHz
Beam direction	−6.5º (azimuth angle), 48º (zenith angle)
Beam width	10º horizontally, 22º vertically

Table 2. Observational mode for *E*- and *F*-region FAIs.

Parameter	*E*-region FAIs	
Pulse repetition frequency	400 Hz	150 Hz
Interpulse period	1.5 ms	6.6 ms
Pulse width	6 μs	32 μs
Range resolution	900 m	4.8 km

Our VHF radar consists of a transmitter, transceiver, and two-computers for analysis and acquisition. Raw data is acquired at 14 bit sampling resolution and ±2V input range. The complex time series of the decoded and integrated raw data signal samples are subjected to the process of fast Fourier transform for on-line computation of the Doppler power spectra for each range bin of the selected range window. The processing of these Doppler power spectra involves the removal of DC, the estimation of the average noise levels, the removal of interference, incoherent integration, and the computation of the three low-order moments. As a method of post-analysis for the raw data, Ionospheric Doppler Beam Steering (IDBS) analysis provides estimates of the Doppler velocity, spectral width, signal-to-noise ratio (SNR), and power for a number of transmitted beam directions. IDBS analyzed data are written to a Solid State Drive disk in a binary format. During continuous data acquisition, each analyzed data file begins at 00:00 universal time (UT).

During the radar observation periods, ionograms at every 15-min interval have been obtained using a digital ionosonde, having a sweep frequency range from 1 to 20 MHz, operated routinely from Icheon (37.14°N, 127.54°E, 27.7°N dip latitude), which is 100 km north of Daejeon. We obtained three parameters of E_s: virtual height of E_s ($h'E_s$); top frequency (f_tE_s), the maximum frequency at which the *E*-region echoes are observed; and blanketing frequency (f_bE_s), the lowest frequency at which the *F*-layer echoes are observed.

Figure 1 shows the view of the Daejeon radar site. Figure 2 illustrates the geometry of the Daejeon radar and Icheon ionosonde experiments. The locations of the radar and ionosonde are marked with a black dot and a black square, respectively. The ground loci of the geomagnetic field lines corresponds to the altitudes perpendicular to the radar beam. The number 200, for example, indicates the ground footprint of the geomagnetic field line that is perpendicular to the radar ray path at an altitude of 200 km.

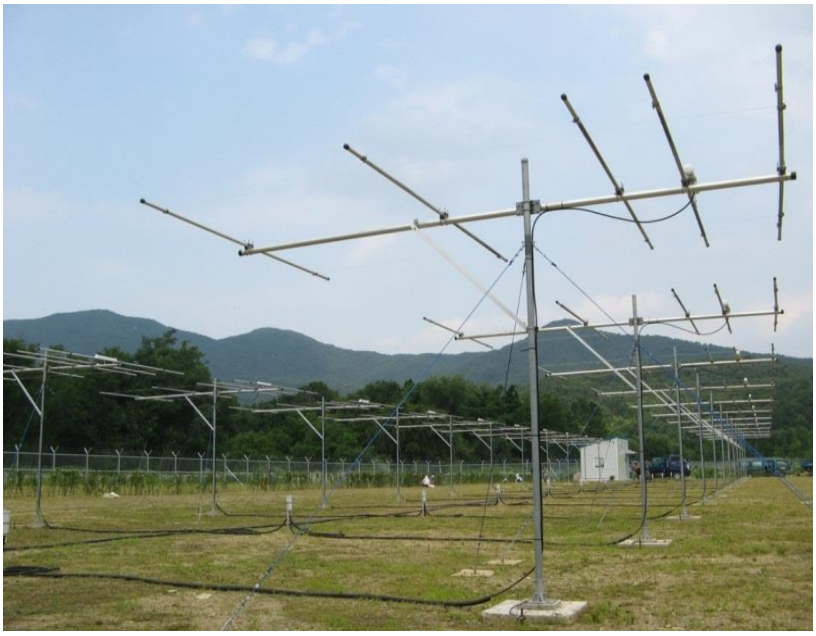

Figure 1. The view of the Daejeon 40.8 MHz VHF radar site.

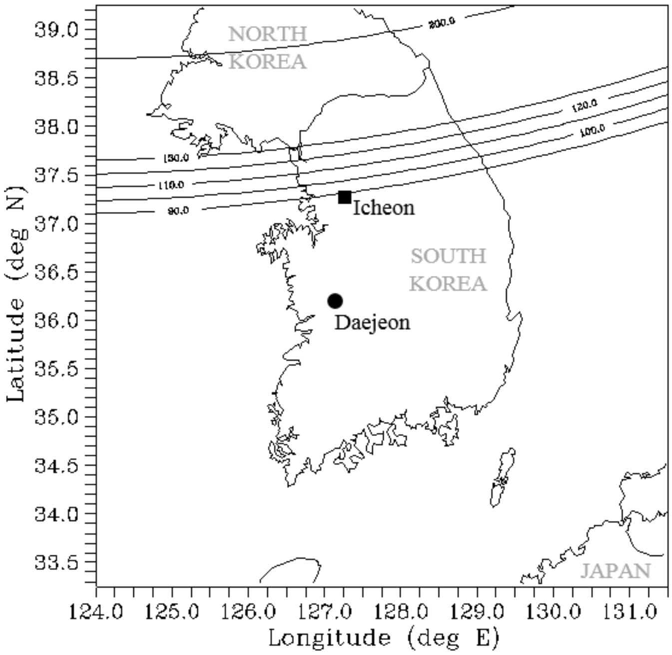

Figure 2. Map showing the locations of the Daejeon coherent scatter radar and the Icheon ionosonde in South Korea.

Results and Discussion:

(1) Characteristics of the *E*- and *F*-region field-aligned irregularities in middle latitudes: Initial results obtained from the Daejeon 40.8 MHz VHF radar in South Korea [*J. Astron. Space Sci.*, *31(1)*, 15-23, 2014].

We have been operating the radar to study ionospheric FAIs since its installation in December 2009. Data were collected in the power spectral form and stored for post-analysis. Later, spectral characteristics were parameterized in terms of signal-to-noise ratio (SNR), Doppler velocity, and spectral width.

We introduce initial observations of *E*- and *F*-region FAIs during the solar minimum (2009–2010) using the 40.8 MHz coherent backscatter radar at Daejeon (36.18°N, 127.14°E, 26.7°N dip latitude) in South Korea. In the *E* region, QP-type echoes appear in the post-sunset period above an altitude of 105 km and continuous-type echoes appear in post-sunrise period around an altitude of 105 km (See Figures 3 and 4). The QP echoes occur intermittently with a quasi-period of 10–20 min and descend to lower altitudes as time progresses. The striations in the QP echoes show negative slopes on the time and altitude frame. While most of the characteristics of the *E*-region QP and continuous echoes observed at Daejeon are consistent with those observed by the MU radar in Japan, the height of the *E*-region QP and continuous echoes observed by the Daejeon radar is seen to be higher by about 5 km than that observed by the MU radar.

In the *F* region, FAIs appear mostly at night in the altitude range of 250–450 km (See Figure 5). Most of these echoes look like patches that last for a few hours. In general, the height of the FAIs increases during pre-midnight and decreases during post-midnight. The duration of the *F*-region FAIs is typically a few hours at night, although, in rare cases, FAIs persist throughout the night. The *F*-region FAIs after sunrise are a new finding by the Daejeon radar. Striation and periodic variation of the striation direction of the FAIs are observed in the *F* region. The striations of negative and positive slopes on the time-height frame are consistent with observations of negative and positive Doppler velocities, respectively. The striation of the *F*-region echoes and the periodic variation of the Doppler velocity, depending on the direction of the striation, were also identified by the MU radar in Japan.

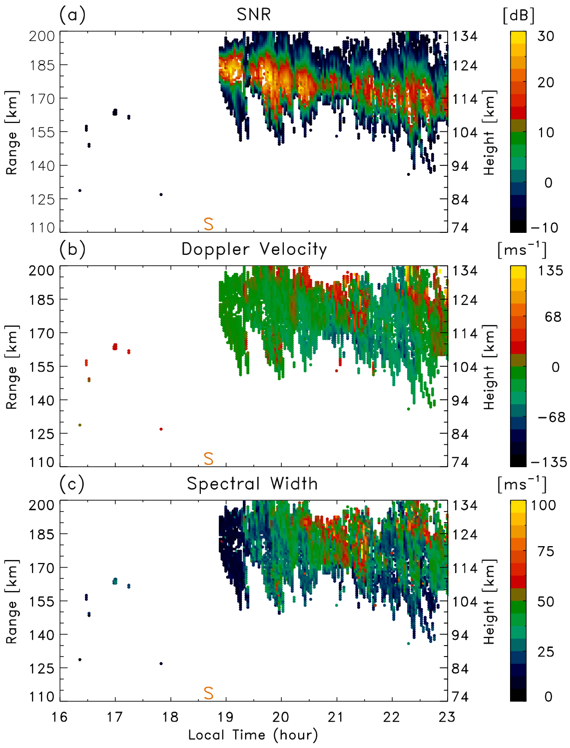

Figure 3. Range-time variation of (a) SNR, (b) Doppler velocity, and (c) spectral width of the *E*-region QP echoes observed on 24 February 2010. 'S' denotes the sunset time

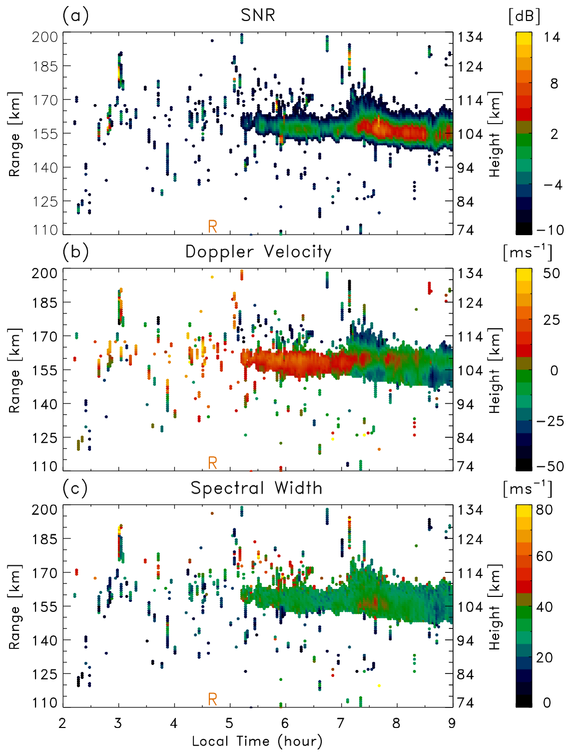

Figure 4. Range-time variation of (a) SNR, (b) Doppler velocity, and (c) spectral width of the *E*-region continuous echoes observed on 2 June 2010. 'R' denotes the sunrise time.

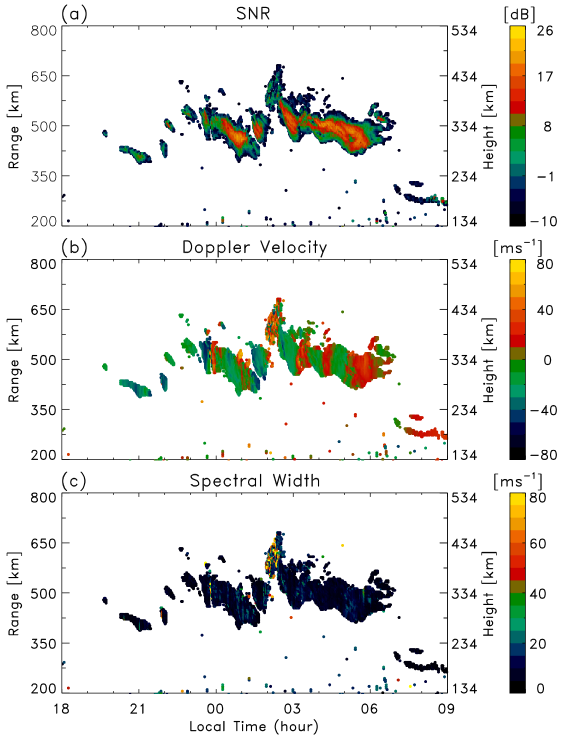

Figure 5. Range-time variation of (a) SNR, (b) Doppler velocity, and (c) spectral width of *F*-region FAIs observed on 23–24 February 2010.

(2) Occurrence climatology of *F*-region field-aligned irregularities in middle latitudes as observed by a 40.8 MHz coherent scatter radar in Daejeon, South Korea [*J. Geophys. Res.*, *120*, 10,107–10,115, 2015].

The 40.8 MHz coherent radar in Daejeon, South Korea provided a unique data source for the statistical study of *F*-region FAI activity in the northern middle latitudes. We have investigated the characteristics and occurrence climatology of *F*-region FAIs by analyzing the Daejeon radar data acquired between 2010 and 2014. The new findings can be summarized as follows.

1. We have identified a repeated occurrence of FAIs at specific LT and altitude zones, and have classified them as post-sunset FAIs (LT: 18:00–21:00 LT, altitude: 250–350 km), nighttime FAIs (LT: 21:00–03:00 LT, altitude: 350–450 km), pre-sunrise FAIs (LT: 02:00–05:00 LT, altitude: 250–350 km), and post-sunrise FAIs (LT: 05:00–09:00 LT, altitude: 160–300 km) (See Figure 6).
2. The occurrence rate of post-sunrise FAIs is largest during the equinoxes, whereas the occurrence rate of nighttime FAIs is largest during summer. The occurrence rates of post-sunset and nighttime FAIs are greater than those of pre-sunrise and post-sunrise FAIs (See Figure 7).
3. Post-sunset FAIs are the most pronounced feature in terms of the occurrence rate and SNR (See Figure 8).
4. Post-sunrise FAIs often consist of two thin layers.
5. The FAI occurrence tends to increase with an increase in solar flux (See Figure 9).
6. The Doppler velocity and spectral width observed by the Daejeon radar are a few times smaller than those observed by the MU radar (See Figure 10).

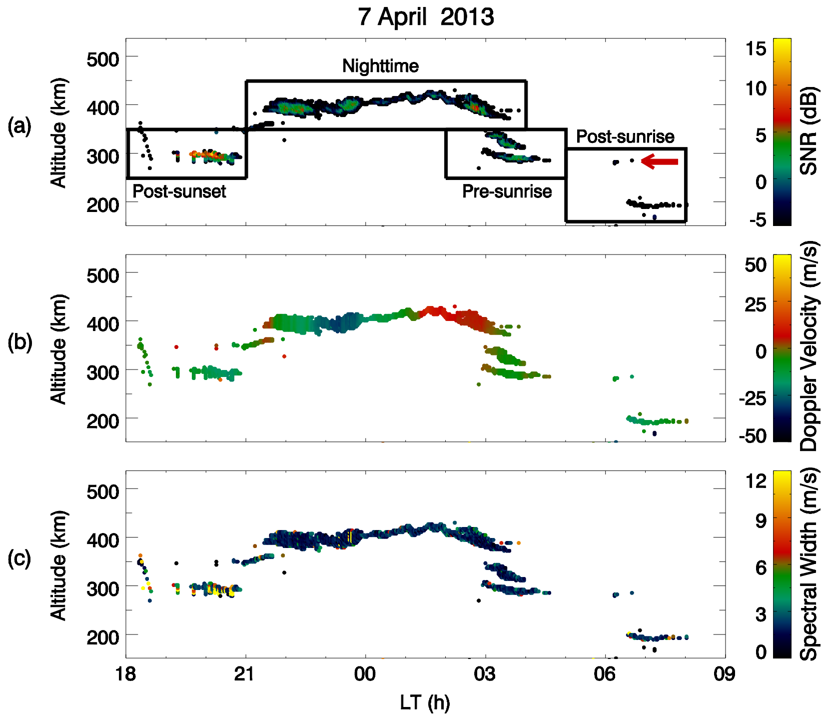

Figure 6. The local time (LT)-altitude distributions of (a) the signal-to-noise ratio (SNR), (b) the Doppler velocity, and (c) the spectral width for the observations on 7 April 2013. Post-sunset, nighttime, pre-sunrise, and post-sunrise field-aligned irregularities (FAIs) are indicated by black boxes in Figure 6a.

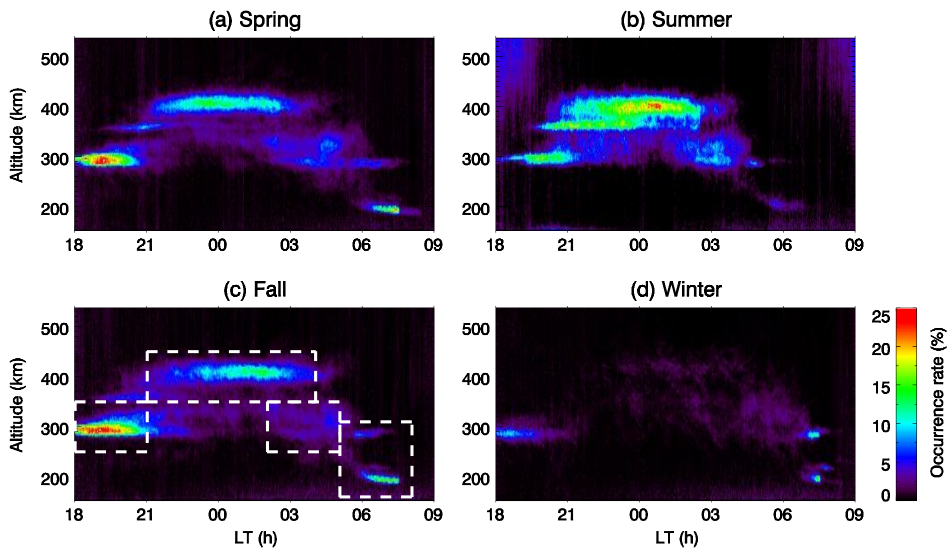

Figure 7. Distribution of the field-aligned irregularity (FAI) occurrence rate during (a) spring (February, March, April), (b) summer (May, June, July), (c) fall (August, September, October), and (d) winter (November, December, January).

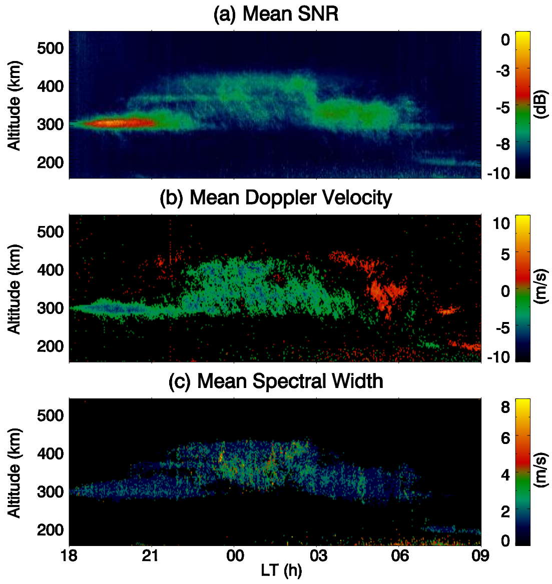

Figure 8. The local time (LT)-altitude distributions of (a) the mean SNR, (b) the mean Doppler velocity, and (c) the mean spectral width.

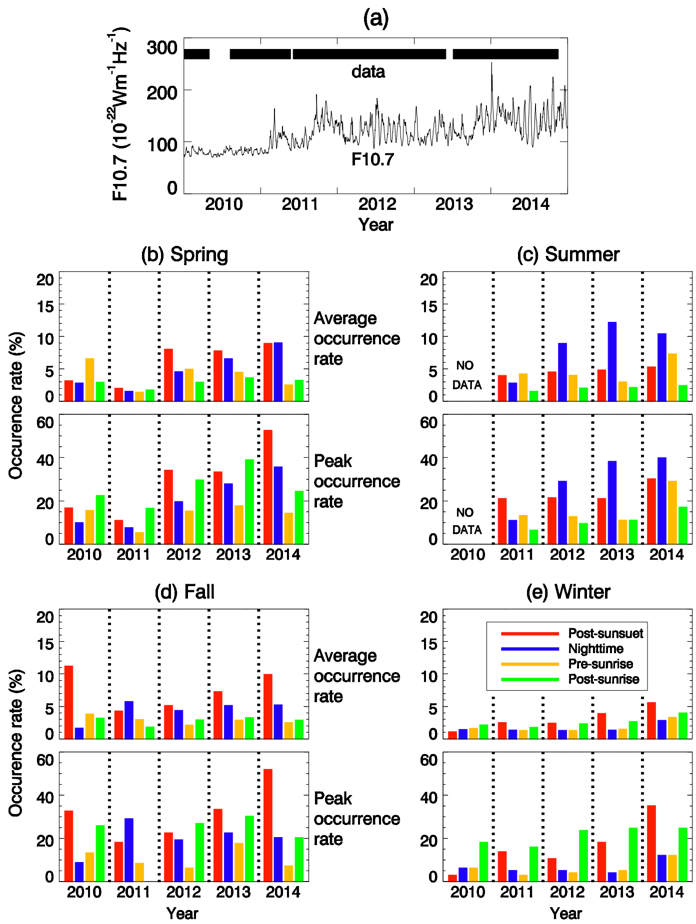

Figure 9. (a) F10.7 index and Daejeon radar observation days. Yearly variation of post-sunset (red bars), nighttime (blue bars), pre-sunrise (yellow bars), and post-sunrise (green bars) field-aligned irregularities (FAIs) during (b) spring, (c) summer, (d) fall, and (e) winter.

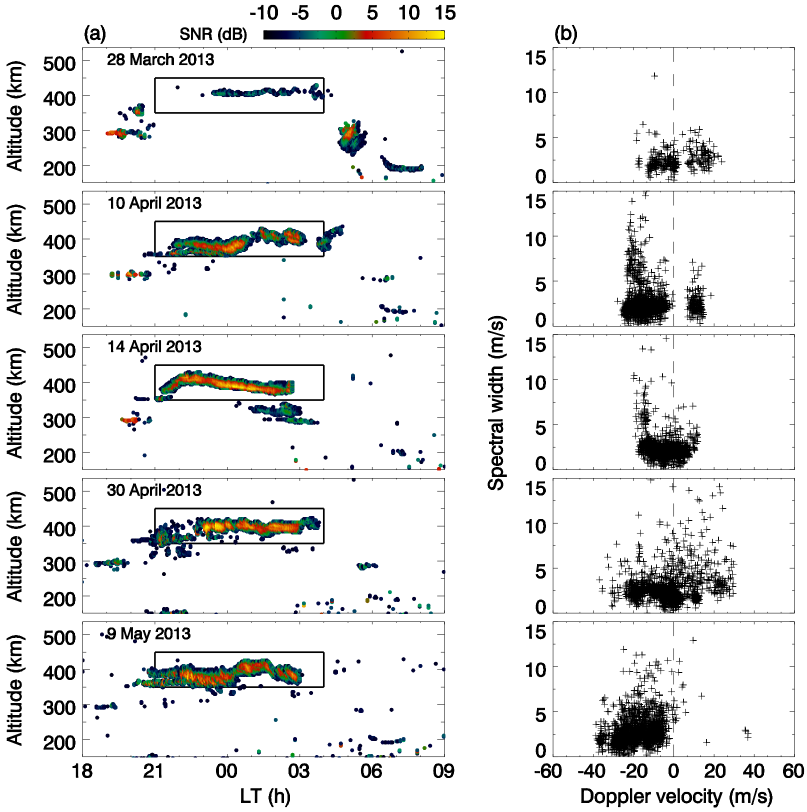

Figure 10. (a) The local time (LT)-altitude distributions of the signal-to-noise ratio (SNR) on five nights. (b) The relationship between the Doppler velocity and spectral width for nighttime field-aligned irregularities (FAIs) indicated by black boxes in Figure 10a.

Our knowledge of FAIs in the middle latitudes relies on the observations by the MU radar. In comparison with the MU radar observations, some features are seen only by the Daejeon radar. Significant differences in the FAI characteristics also exist between the Daejeon and MU radar observations. In this section, we discuss the similarities and differences of the two radar observations.

For Daejeon radar observations, we were able to divide the FAIs into four types, depending on their occurrence with respect to the LT and altitude coordinates. In previous studies with MU radar observations [*Fukao et al.*, 1988, 1991], however, FAIs appeared only between 21:00 and 04:30 LT. The FAIs at this time interval correspond to nighttime and pre-sunrise FAIs. In other words, post-sunset and post-sunrise FAI features did not appear in the MU radar observations. The absence of those FAIs in the MU radar observations may not be attributed to the longitudinal or latitudinal variability of the FAIs, because the differences of the geographic longitude and latitude between the Daejeon and MU radar locations are only 8.96º and 1.29º, respectively. Considering the fact that the occurrence rate of those FAIs during summer is less than 10%, it is possible that those FAIs did not occur during the campaign periods of the MU radar.

Because the MU radar has been operated sparsely, the MU radar observations were not able to produce the FAI distributions shown in Figure 7. *Fukao et al.* [1991] briefly explained that FAIs were detected more frequently during summer than during other seasons, but the occurrence statistics were not presented. Consistent with this statement in *Fukao et al.* [1991], our results show that the occurrence rate of FAIs during summer is greater than that during other seasons when nighttime FAIs are considered. However, post-sunset FAIs behave differently, and their occurrence rate is maximal during the equinoxes.

One might expect a higher FAI occurrence rate during a period of lower solar activity because of the fact that MSTIDs (medium-scale traveling ionospheric disturbances), which are known as an important source of middle-latitude FAIs, have been detected more frequently during a solar minimum than during a solar maximum [*Amorim et al*., 2011; *Candido et al*., 2008; *Duly et al*., 2013; *Kotake et al*., 2006, 2007; *Martinis et al*., 2010; *Otsuka et al*., 2011, 2013]. In fact, *Fukao et al.* [1991] briefly stated that they observed the FAIs more frequently during a period of low solar activity than during a period of high solar activity. However, our results show an increase in the FAI occurrence rate with an increase in solar activity. This result may provide a clue as to the source of the middle-latitude FAIs. Middle-latitude *F*-region FAIs are often explained in association with MSTIDs [*Otsuka et al.*, 2009]. The high occurrence rate of the FAIs during summer is consistent with the high occurrence rate of MSTIDs during summer. However, the increase of the FAI occurrence rate with an increase in solar activity is inconsistent with the solar cycle dependence of the MSTID activity.

In addition to MSTIDs, a plausible FAI source should show an increase in its activity with an increase in solar activity. Several studies have reported the association of *F*-region FAIs with the *E* region [*Yokoyama and Hysell*, 2010; *Yokoyama et al.*, 2009]. The numerical simulation results of *Yokoyama et al.* [2009] showed that sporadic *E* (*Es*)-layer instability plays a major role in seeding the structure of electron density in the *F* region. Considering the close connection between meteors and *Es* [*Haldoupis et al*., 2007], as well as the increasing tendency of the meteor count with an increase in solar activity [*Šimek and Pecina*, 2002], *Es* can indeed be a plausible candidate for the source of the FAIs. The high occurrence rate of FAIs during summer is also consistent with the peak occurrence rate of meteors during summer. We are not able to verify the correlation between the *F* region FAIs and *Es* (or *E* region FAIs) because no observation is available at the footprint of the *F* region in North Korea. In comparison with the *E* region FAIs observed over South Korea by the Daejeon radar (not shown), the high occurrence rates of the *E*- and the *F*-region FAIs in summer are consistent. However, the solar cycle dependence of the *E*- and the *F*-region FAIs is inconsistent. The coupling between the *E*- and the *F*-region FAIs is difficult to assess using the Daejeon radar observations because the *E* region FAIs are not observed exactly at the footprint of the *F* region FAIs. We postpone the investigation of the coupling between the *E*- and the *F*-region FAIs after we have knowledge of the spatial variability of the *E* region FAIs.

Finally, we point out the difference of the Doppler velocity and spectral width between the two radar observations. In MU radar observations, the Doppler velocity of the FAIs varies between −100 and 200 m/s, and the spectral width ranges between 5 and 50 m/s. However, the Doppler velocity and spectral width of the FAIs observed by the Daejeon radar are smaller about 3~5 times compared with those observed by the MU radar. The coordination of a simultaneous operation of the Daejeon and MU radars in the future will be an effective way to clarify such discrepancies, and also to identify the variability of the FAI in the local region.

(3) First report on the afternoon E-region plasma density irregularities in middle latitude [submitted to *ASR*]

The In this paper, for the first time, we report the afternoon observations of the mid-latitude *E*-region FAIs made by the Daejeon radar. Figures 11a-11c present the range-time variations of SNR, Doppler velocity, and spectral width between 09:00 and 23:00 LT on 22 June 2011. Echo height is on the right side and is obtained by multiplying Cos 48° (=0.669) by the echo range. For the morning time from 09:00 to 10:00 LT, the weak continuous type echoes (SNR ≤ 10 dB) are found at altitudes between 105 and 110 km. In the post-sunset period just after sunset (20:25 LT), strong QP type echoes (maximum SNR ~ 30 dB) are observed at about 120 to 140 km altitude. While the characteristics of the post-sunrise continuous and post-sunset QP echoes in middle latitudes have already been known from the MU radar observations [e.g., *Yamamoto et al*., 1991, 1992, 1994; *Ogawa et al*., 1995, 2002], little was known about the mid-latitude *E*-region echoes in the afternoon from noon to sunset. Indeed, although radar probing of the mid-latitude *E*-region ionospheric electron density irregularities has been carried out for several decades, no the afternoon *E*-region FAIs in middle latitude have been reported yet. In Figure 11a, however, at Daejeon, very strong continuous-like type afternoon echoes are seen at about 100 to 135 km altitude with thickness of 35 km, centered at the altitude of about 115 km, from 14:00 to 20:30 LT. The maximum SNR of the echoes is ~30 dB. This value is similar to that of the post-sunset QP echoes and is stronger than that of the post-sunrise continuous echoes. In Figure 11b, The Doppler velocities are almost positive except for them between 16:00 and 17:30 LT, indicating that FAIs are moving away from the radar (or upward velocities). The absolute magnitude of the Doppler velocities of the afternoon echoes is mostly less than 30 m s^{-1}. This magnitude is smaller than that in the post-sunset QP echoes and is similar to that of the post-sunrise continuous echoes. In Figure 11c, the spectral widths of the Doppler velocity of the afternoon echoes are mostly very low (maximum spectral width ~ 10 m s^{-1}). This magnitude is smaller than those of the post-sunset QP and the post-sunrise continuous echoes.

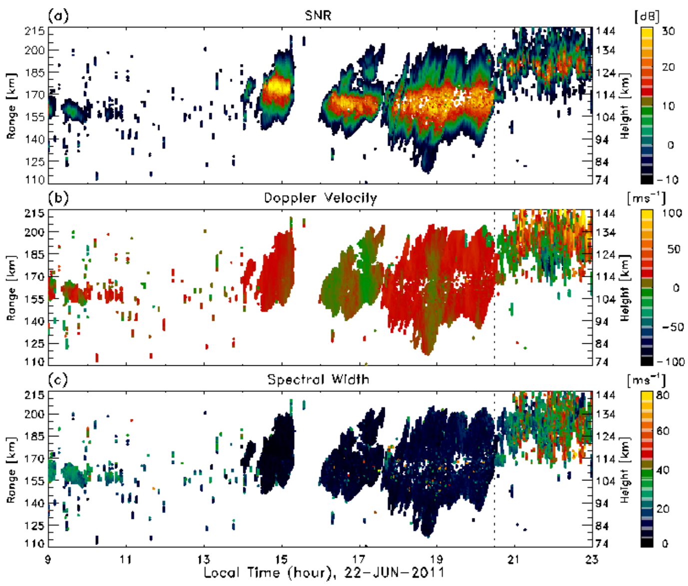

Figure 11. Range-time variations of (a) signal-to-noise ratio (SNR), (b) Doppler velocity and (c) spectral width of the *E*-region irregularities observed on 22 June 2011. Vertical dotted line represents sunset time in the *E* region.

Figure 12 illustrates the seasonal percentage occurrence of the afternoon *E*-region FAIs as a function of local time observed from the Daejeon VHF radar for spring (March, April, May), summer (June, July, August), fall (September, October, November), and winter (December, January, February) seasons during 2011-2012. It is observed that the occurrence of afternoon *E*-region FAIs has a strong seasonal dependence with maximal occurrence during summer season, minimal occurrence during winter season, and moderate occurrence during equinox season. The afternoon *E*-region FAIs for summer season is more likely to occur at 12-20 LT with a peak occurrence (~29 %) around 19-20 LT. For winter season, the peak occurrence (~5 %) of afternoon *E*-region FAIs is seen around 15-16 LT. The occurrence of afternoon *E*-region FAIs for equinox is higher than one for winter solstice, which is particularly due to the enhanced occurrence of afternoon *E*-region FAIs during autumnal equinox.

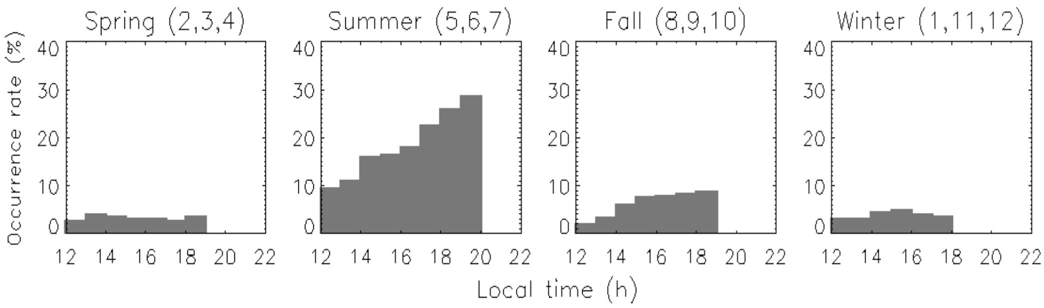

Figure 12. Seasonal percentage occurrence of the afternoon *E*-region FAIs as a function of local time observed at Daejeon, South Korea, during 2011-2012.

Figures 13a-13d present percentage distributions of the SNR, Doppler velocity and spectral width and height of the afternoon *E*-region FAIs observed from the Daejeon VHF radar during 2011-2012. The SNRs vary between −10 and 35 dB, with maximum occurrence probability as high as 29% about −10 dB. Doppler velocities are found to be mostly within ±40 m s^{-1}, with maximum occurrence probability as high as 38% about −10 m s^{-1}. Most spectral widths are close to zero. This indicates that the strong irregularities are not related to turbulent plasma motions. The afternoon *E*-region FAIs occur around 100-135 km altitudes.

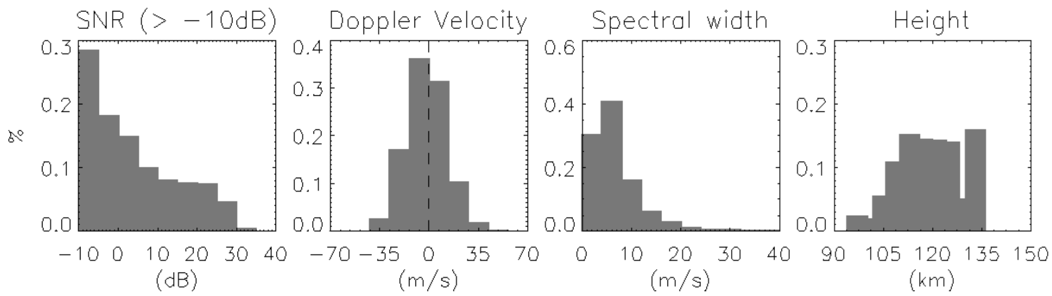

Figure 13. The percentage distributions of (a) SNR, (b) Doppler velocity, (c) spectral width, and (d) height of the afternoon *E*-region FAIs during 2011-2012.

Here we investigate the relationship between the afternoon *E*-region FAIs at a middle latitude and variations of the E_s layers. For this purpose, we present variations of the E_s parameters observed from Icheon ionosonde and compare these with the variations of FAIs observed over Daejeon. In Figures 14a and 14b, we present examples of SNR of afternoon *E*-region FAIs observed by the Daejeon radar and the virtual height of E_s ($h'E_s$) by Icheon ionosonde on 22 June and 28 July 2011. Color contours represent the range-time SNR maps of the afternoon *E*-region FAIs and circle-solid lines in green color represent $h'E_s$. These figures clearly show that the average height of $h'E_s$ falls mostly in the height range of 105-110 km and these heights will be 5-10 km greater than the FAI bottom side. The high altitude values commonly observed during daytime can be attributed to the group retardation effect on the HF frequencies during daytime due to underlying ionization. *Lee et al.* [2000] found the virtual height of E_s in the range of 100-110 km and considered that these heights will be 5-10 km greater than true heights depending on the underlying ionization.

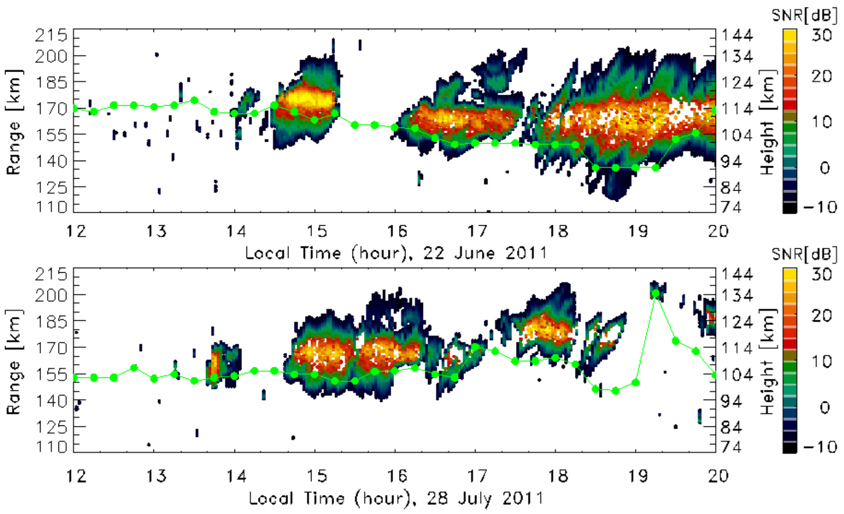

Figure 14. Observations of the afternoon *E*-region FAIs and E_s on (a) 22 June 2011 and (b) 28 July 2011. Color contours and circle-solid lines in green color represent range-time SNR maps of the afternoon *E*-region FAIs and $h'E_s$ for each day, respectively.

According to recent studies on the interpretation of mid-latitude E_s [*Hussey et al.*, 1998; *Maruyama et al.*, 2006; *Ogawa et al.*, 2002], the top frequency (f_tE_s) corresponds to either local maximum electron density in a non-uniform layer or peak electron density in a spatially uniform layer and the blanketing frequency (f_bE_s) corresponds to the minimum value among the peak electron densities in a layer. For a non-uniform E_s layer, the difference between f_tE_s and f_bE_s is shown to be related to irregularities present in the E_s layer, albeit at large scale than those observed by VHF radars. In this study, we have used f_tE_s and f_bE_s as a representative of the maximum and minimum values of peak electron densities in the E_s layer, respectively; and (f_tE_s - f_bE_s) as representative of irregularities. Figure 15 shows seasonal and local time distributions of *Es* parameters and observed from Icheon ionosonde and peak SNR of the afternoon *E*-region FAIs observed from Daejeon radar in 2011 and 2013. In these figures, we have shown f_tE_s in the top panels, f_bE_s in the second panels, (f_tE_s - f_bE_s) in the third panels, and peak SNR of the afternoon *E*-region echoes in the bottom panels. In regard to relationship of afternoon FAIs with E_s activities, as is evident from these figures, SNR of the afternoon *E*-region FAIs are poorly correlated with both f_tE_s and f_bE_s and fairly well correlated with (f_tE_s - f_bE_s). Almost no correlation found between FAIs and f_bE_s suggests that commonly occurring blanketing E_s is not sufficient for the generation of afternoon irregularities in the mid-latitude *E* region. Instead, it suggests that large values of (f_tE_s - f_bE_s) enhance the SNR of FAIs, suggesting that patchy type E_s structures must be responsible for the excitation of irregularities.

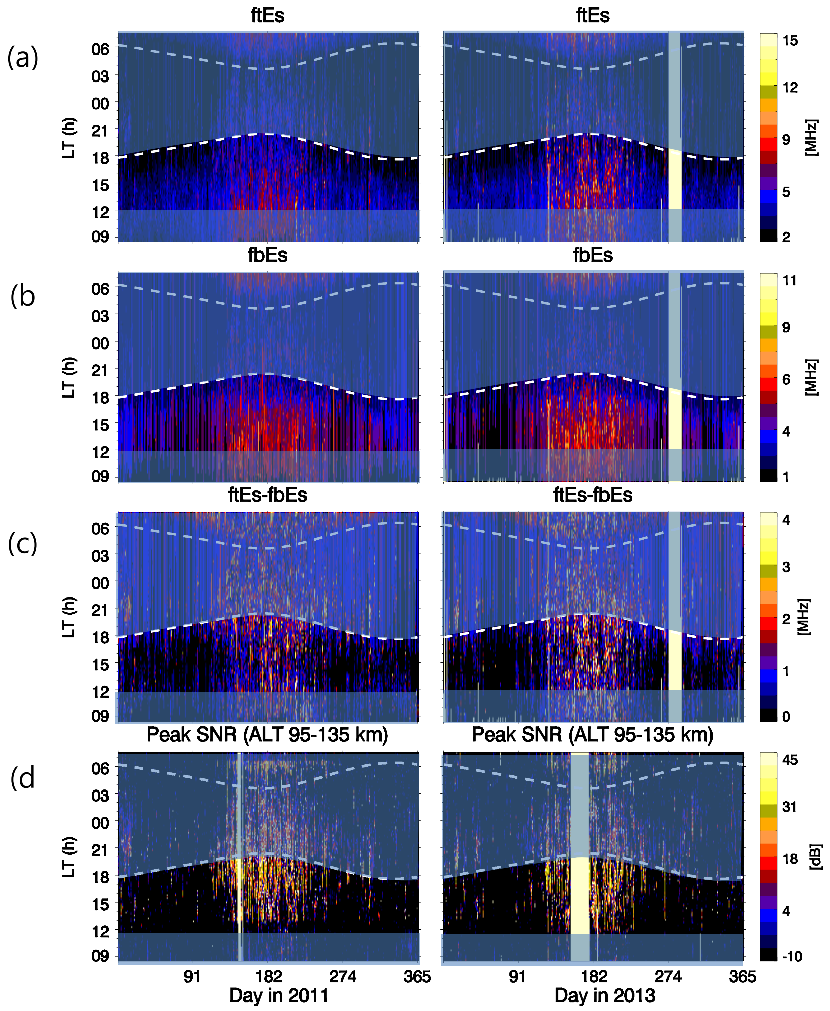

Figure 15. (a-c) Seasonal and local time distributions of the three E_s parameters (f_tE_s, f_bE_s and f_tE_s-f_bE_s) observed from Icheon ionosonde and (d) peak SNR of *E*-region FAIs observed from Daejeon VHF radar in 2011 and 2013.

Using the MU radar and ionosonde from Shigaraki in Japan, *Yamamoto et al*. [1992] found that the QP radar echoes from the mid-latitude *E* region in the nighttime correlated with E_s activity. Also, based on simultaneous observations of FAIs and E_s from middle latitude, *Ogawa et al*. [2002] and *Maruyama et al*. [2006] found good correlation between the QP radar echoes and the enhanced value of (f_tE_s - f_bE_s). *Yamamoto et al*. [1992], however, found that the radar echoes from the mid-latitude *E* region were not detected in the summer afternoon when ionosonde observed maximum E_s activity. Similar results have been reported from Chung-Li, Tiwan [*Lee et al*., 2000]. On the other hand, *E*-region observations from Daejeon VHF radar and Icheon ionosonde clearly show that afternoon FAIs are detected significantly, especially in summer season, and are correlated with E_s (especially, f_tE_s - f_bE_s). Based on these different observations in mid-latitude *E* region, the generation of FAIs is closely related to localized density gradients within the E_s layer that provide favorable conditions for the growth of instability.

List of Publications and any Significant Collaborations that resulted from your AOARD supported project:

a) Papers published in peer-reviewed journals

1. Kwak, Y.-S., and A. D. Richmond (2017), Relative contributions of momentum forcing and heating to high-latitude lower thermospheric winds, *J. Geophys. Res. Space Physics, 121*, doi:10.1002/2016JA023124.

2. Park, J., H. Luehr, G. Kervalishvili, J. Rauberg, C. Stolle, Y.-S. Kwak, and W. K. Lee (2017), Morphology of high-latitude plasma density perturbations as deduced from the total electron content measurements onboard the Swarm constellation, *J. Geophys. Res. Space Physics, 122*, 1338–1359, doi:10.1002/2016JA023086..

3. Choi, J.-M, H. Kil, Y.-S. Kwak, J. Park, W. K. Lee, and Y. H. Kim (2017), Periodicity in the occurrence of equatorial plasma bubbles derived from the C/NOFS observations in 2008–2012, *J. Geophys. Res. Space Physics, 122*, 1137–1145, doi:10.1002/2016JA023528.

4. Park, J., H. Luhr, D. J. Knudsen, J. K. Burchill, and Y.-S. Kwak (2017), Alfven waves in the auroral region, their Poynting flux, and reflection coefficient as estimated from Swarm observations, *J. Geophys. Res. Space Physics*, *122*, 2345–2360, doi:10.1002/2016JA023527.

5. Lee, Y.-S., Y.-S. Kwak, K.-C. Kim, B. Solheim, R. Lee, and J. Lee (2017), Observation of atomic oxygen O(1S) green-line emission in the summer polar upper mesosphere associated with high-energy (≥ 30 keV) electron precipitation during high-speed solar wind streams, J. Geophys. Res. Space Physics, 121, doi:10.1002/2016JA023413.Park, Jaeheung, Hyosub Kil, Claudia Stolle, Hermann Luhr, William R. Coley, Anthea Coster, and Young-Sil Kwak (2016), Daytime mid-latitude plasma depletions observed by Swarm: Topside signatures of the rocket exhaust, *Geophys. Res. Lett*., *43*, doi:10.1002/2016GL067810.

6. Park, J., H. Luehr, C. Stolle, J. Rodriguez-Zuluaga, D. J. Knudsen, J. K. Burchill, and Y.-S. Kwak (2016), Statistical survey of nighttime mid-latitude magnetic fluctuations: Their source location and Poynting flux as derived from the Swarm constellation, *J. Geophys. Res. Space Physics, 121*, doi:10.1002/2016JA023408.

7. Lee, Young-Sook, Sheila Kirkwood, Young-Sil Kwak, and Jaejin Lee (2016), Evidence for Long-Lasting Electrical Leader Discharges in Non-Specular Meteor Trails Observed In the Summer Polar Upper Mesosphere, *Research Inventy: International Journal of Engineering And Science, Vol.6,* Issue 7 (August 2016), PP -36-42.

8. Park, Jaeheung, Hyosub Kil, Claudia Stolle, Hermann Luhr, William R. Coley, Anthea Coster, and Young-Sil Kwak (2016), Daytime mid-latitude plasma depletions observed by Swarm: Topside signatures of the rocket exhaust, *Geophys. Res. Lett*., *43*,

doi:10.1002/2016GL067810.

9. Park, J., C. R. Martinis, H. Luhr, R. F. Pfaff, and Y.-S. Kwak (2016), Hemispheric asymmetry in transition from equatorial plasma bubble to blob as deduced from 630.0 nm airglow observations at low latitudes, *J. Geophys. Res. Space Physics*, *121*, doi:10.1002/2015JA022175.

10. Yang, T.-Y., Y.-S. Kwak, H. Kil, Y.-S. Lee, W. K. Lee, and J.-J. Lee (2015), Occurrence climatology of F region field-aligned irregularities in middle latitudes as observed by a 40.8 MHz coherent scatter radar in Daejeon, South Korea, *J. Geophys. Res. Space Physics*, *120*, 10,107–10,115, doi:10.1002/2015JA021885.

11. Park, J., H. Luhr, G. Kervalishvili, J. Rauberg, I. Michaelis, C. Stolle, and Y.-S. Kwak (2015), Nighttime magnetic field fluctuations in the topside ionosphere at midlatitudes and their relation to medium-scale traveling ionospheric disturbances: The spatial structure and scale sizes, *J. Geophys. Res. Space Physics*, *120*, doi:10.1002/2015JA021315.

12. Park, J., H. Luhr, M. Nishioka, and Y.-S. Kwak (2015), Plasma density undulations correlated with thermospheric neutral mass density in the daytime low-latitude to midlatitude topside ionosphere, *J. Geophys. Res. Space Physics, 120*, doi:10.1002/2015JA021525.

13. Kil, H., Y.-S. Kwak,W. K. Lee, E. S. Miller, S.-J. Oh, and H.-S. Choi (2015), The causal relationship between plasma bubbles and blobs in the low-latitude F region during a solar minimum, *J. Geophys. Res. Space Physics, 120*, 3961–3969, doi:10.1002/2014JA020847.

14. Kil, H., Y.-S. Kwak, W. K. Lee, J. Krall, J. D. Huba, and S.-J. Oh (2015), Nonmigrating tidal signature in the distributions of equatorial plasma bubbles and prereversal enhancement, *J. Geophys. Res. Space Physics*, *120*, 3254–3262, doi:10.1002/2014JA020908.

15. Lee, Y.-S., S. Kirkwood, Y.-S. Kwak, G. G. Shepherd, K.-C. Kim, T.-Y. Yang, and A. Kero (2015), Characteristics of PMSE associated with the geomagnetic disturbance driven by corotating interaction region and high-speed solar wind streams in the declining solar cycle 23, *J. Geophys. Res. Space Physics*, *120*, doi:10.1002/2015JA021144.

16. Lee, W. K., H. Kil, Y.-S. Kwak, and L. J. Paxton (2015), Morphology of the postsunset vortex in the equatorial ionospheric plasma drift, *Geophys. Res. Lett.*, *42*, 9–14, doi:10.1002/2014GL062019.

17. Kwak, Young-Sil, Tae-Yong Yang, Hoysub Kil, Devulapalli Venkata Phanikumar, Bok-Haeng Heo, Jae-Jin Lee, Junga Hwang, Seong-Hwan Choi, Young-Deuk Park, and Ho-Seong Cho (2014), Characteristics of the *E*- and *F*-region field-aligned irregularities in middle latitudes: Initial results obtained from the Daejeon 40.8 MHz VHF radar in South Korea, *J. Astron. Space Sci.*, *31(1)*, 15-23.

18. Kil, Hyosub, Young-Sil Kwak, Woo Kyoung Lee, Seung-Jun Oh, Marco Milla, and Ivan Galkin (2014), Broad plasma depletions detected in the bottomside of the equatorial *F* region: simultaneous ROCSAT-1 and JULIA observations, *J. of Geophys. Res.*, *119*, doi:10.1002/2014JA019964.

19. Kil, Hyosub, Woo Kyoung Lee, Young-Sil Kwak, Yongliang Zhang, Larry J. Paxton, and Marco Milla (2014), The zonal motion of equatorial plasma bubbles relative to the background ionosphere, *J. of Geophys. Res.*, *119*, doi:10.1002/2014JA019963.

20. Lee, Young-Sook, Sheila Kirkwood, Young-Sil Kwak, Kyung-Chan Kim, and Gordon G. Shepherd (2014), Polar summer mesospheric extreme horizontal drift speed during interplanetary corotating interaction regions (CIRs) and high-speed solar wind streams: Coupling between the solar wind and the mesosphere, *J. of Geophys. Res.*, *119*, doi:10.1002/2014JA019790.

b) Papers published in peer-reviewed conference proceedings

None

c) Papers published in non-peer-reviewed journals and conference proceedings

None

d) Conference presentations without papers

1. Jaeheung Park, Hermann Lühr, Claudia Stolle, and Young-Sil Kwak, Observing plasma and field irregularities in the terrestrial ionosphere by the European Space Agency's Swarm constellation, *11th IAA Symposium on Small Satellites for Earth Observation*, Apr/24~28/2017.

2. Young-Sil Kwak and Arthur D. Richmond, Analysis of the steady-state eddy available energy budget in the high-latitude lower thermosphere, *American Geophysical Union (AGU) Fall Meeting*, Dec/12~16/2016.

3. Hyosub Kil, Larry Paxton, Yongliang Zhang, Robert Schaefer, and Young-Sil Kwak, Remote sensing of the ionosphere and thermosphere using a space-borne FUV imager (TIMED/GUVI), *American Geophysical Union (AGU) Fall Meeting*, Dec/12~16/2016.

4. Jaeheung Park and Young-Sil Kwak, Ionospheric irregularities observed by the paired Swarm satellites, *Korea Space Science Society(KSSS) Fall Meeting*, Oct/27~28/2016.

5. Young-Sil Kwak, Jaeheung Park, Jae-Woo Park, Ho-Cheol Jeon, Tae Young Kim, Jun-Chul Mun, Hyun-Jun Jin, Jong-Hyeon Kim, and Terry Bullett, Ionospheric oblique incident sounding observations between Korea and Japan: Preliminary results, *Korea Space Science Society(KSSS) Fall Meeting*, Oct/27~28/2016.

6. Jeong Heon Kim, Yong Ha Kim, and Young Sil Kwak, Verification of a revised version of SAMI2 with the observed ionospheric data over the Korean peninsula, *Asia-Oceania Space Weather Alliance Workshop*, Oct/24~26/2016.

7. Ji-Hee Lee, Young-Sil Kwak, Geonhwa Jee, and Young-Sook Lee, Response of nitric oxide(NO) to high-speed solar wind stream in high-latitude lower thermosphere and mesosphere, *CEDAR Workshop*, Jun/19~24/2016.

8. Young-Sil Kwak, Tae-yong Yang, Hyosub Kil, Young-Sook Lee, and Jaejin Lee, The first report on the afternoon *E*-region plasma density irregularities in middle latitude, *Korea Space Science Society (KSSS) Spring Meeting*, Apr/29~30/2015.

9. Jaeheung Park and Young-Sil Kwak, Low- and mid-latitude ionosphere as observed by the Swarm constellation, *Korea Space Science Society(KSSS) Spring Meeting*, Apr/29~30/2015.

10. Young-Sil Kwak, Hyosub Kil, and Woo Kyoung Lee, Seasonal, diurnal, and solar cycle variations of the thermospheric neutral mass density structure in low latitudes, *IUGG General Assembly*, Jun/23~28/2015.

11. Young-Sil Kwak, Tae-Yong Yang, Hyosub Kil, Young-Sook Lee, and Jaejin Lee, Observation of ionospheric irregularities using VHF radar in Daejeon, South Korea, *KASI-Nagoya joint space weather workshop*, Oct/12~13/2015.

12. Young-Sook Lee, Gordon Shepherd, Young-Sil Kwak, and Kyung-Chan Kim, Observation of summer daytime aurora in the noctilucent cloud layer and its link to high-energy particle precipitation during high-speed solar wind streams, *American Geophysical Union (AGU)*

Fall Meeting, Dec/12~19/2015.

13. Young-Sil Kwak, Tae-yong Yang, Hyosub Kil, Young-Sook Lee, and Young-Deuk Park, The Daejeon 40.8 MHz VHF radar observations of the E- and F-region field-aligned irregularities in the middle latitude, *Korea Space Science Society(KSSS) Spring Meeting*, Apr/24~25/2014.

14. Young-Sil Kwak, Tae-Yong Yang, Hyosub Kil, Yuichi Otsuka, and Devulapalli Phanikumar, Characteristics of the Afternoon *E*-region Plasma Density Irregularities in Middle Latitudes, *American Geophysical Union (AGU) Fall Meeting*, Dec/15~19/2014.

15. Tae-Yong Yang, Young-Sil Kwak, Hyosub Kil, Young-Sook Lee, Wookyoung Lee ,and Jae-Jin Lee, Statistical characteristics and occurrences of the F-region field-aligned irregularities in middle latitudes observed with Korea VHF coherent scattering radar, *American Geophysical Union (AGU) Fall Meeting*, Dec/15~19/2014.

16. Jong-Min Choi, Hyosub Kil, Young-Sil Kwak, Woo Kyoung Lee, Yong Ha Kim, P.A.Roddy and O de La Beaujardiere, Periodicity in the occurrence of equatorial plasma bubbles, *American Geophysical Union (AGU) Fall Meeting*, Dec/15~19/2014.

e) <u>Manuscripts submitted but not yet published</u>

1. Lee, Young-Sook, Young-Sil Kwak, Kyung-Chan Kim, Yong-Ha Kim, Jaejin Lee, and Sheila Kirkwood, Intense mesospheric turbulence induced by large plasma/neutral speeds in association with high-energy electron precipitation during high-speed solar wind streams, *Nature – Scientific Reports, Under Review*.

2. Lee, Ji-Hee, Young-Sil Kwak, Young-Sook Lee, Geonhwa Jee, Sang-Bum Hong, Heejin Hwang, and Dae-Young Lee, Responses of nitric oxide to high-speed solar wind stream in the high-latitude mesosphere and lower thermosphere region, *J. of Geophys. Res., under Review*.

3. Kwak, Young-Sil, Tae-Yong Yang, Hyosub Kil, D.V. Phanikumar, Jong-Min Choi, and Jaeheung Park, First report on the afternoon *E*-region plasma density irregularities in middle latitude, *submitted to ASR*.

f) <u>Interactions with industry or with Air Force Research Laboratory scientists or significant collaborations that resulted from this work</u>

1. We organized “Korea(KASI, ROKAF) – US(AFRL, JHUAPL) Cooperation Meeting for Space Weather and Space Surveillance” in Daejeon in Korea during 6 September – 8 September, 2016. During the meeting period, we and AFRL reported results and status associated with “Mid-latitude Plasma Density Irregularities” and “Space Surveillance”.

2. We visited JHUAPL in Maryland during 13-15 March, 2017 in order to discuss substantive collaborative items associated with “Mid-latitude Plasma Density Irregularities”.

3. We attended “U.S. – ROK 2015 Technology Cooperation Subcommittee (TCSC) Meeting” in Busan in Korea during 5 May – 8 May, 2015. During the meeting period, we and AFRL reported meeting results and status associated with “Mid-latitude Plasma Density Irregularities”.

4. We visited AFRL in Dayton in 22 October 2015 in order to share the current status of PA and discuss substantive collaborative items associated with “Mid-latitude Plasma Density Irregularities”.

5. We attended “U.S. – ROK 2014 Technology Cooperation Subcommittee (TCSC) Meeting” in San Diego during 28 April – 2 May, 2014. During the meeting period, we and AFRL

discussed about collaborative ionospheric research topic.

6. We attended "Plasma Instabilities and Turbulence in Space and Laboratory Plasma Sheaths Technical Interchange Meeting (TIM)", which was sponsored by UCLA and AFRL/RYMH, in UCLA during 15 – 16 July 2014. The TIM focused (i) Pulse Power Experiments and Associated Plasma Turbulence, (ii) Ionospheric Turbulence and Impact on Communication Systems, and (iii) Experimental and Simulation Techniques for Plasma Laboratory and Ionospheric Problems. We presented "Characteristics of mid-latitude ionospheric plasma irregularities based on Daejeon VHF radar observations" and "Dynamics and morphology of equatorial plasma bubbles" on session (ii). And KASI-ROK-AFRL-JHU/APL discussed about international collaborative project.

g) Invited talks (event name, title, date)

1. **Event name:** 2016 Asia-Pacific Radio Science Conference (AP-RASC), URSI, Seoul, Korea
   Title: "The Daejeon 40.8 MHz VHF radar observations of the E- and F-region field-aligned irregularities in the middle latitude"
   Date: August 23th, 2016

2. **Event name:** 2016 Asia Oceania Geosciences Society (AOGS) meeting, Beijing, China
   Title: "Relative Contributions of Heating and Momentum Forcing to High-Latitude Lower Thermospheric Winds"
   Date: August 3th, 2016

3. **Event name:** 2015 Story of the night sky for young scientists, Daegu, Korea
   Title: "Space weather and ionosphere/aurora"
   Date: November 20th, 2015

h) Award for best paper, best poster (title, date)

1. **Title:** 2016 "Grand prize award of paper" in Astronomy and Space Science Institute
   Date: September 13th, 2016

2. **Title:** 2015 "Best prize award of paper" in Astronomy and Space Science Institute
   Date: September 13th, 2015

3. **Title:** 2014 "Excellence prize award of paper" in Astronomy and Space Science Institute
   Date: September 13th, 2014

i) Award of fund received related to your research efforts (name, amount, date)

1. **Title:** Ministry of Science, ICT and Future Planning in Korea, "Study on solar activity processes and near-earth space environment changes"
   Amount: $560,000 at 2016
   Date: January 1st, 2016

2. **Title:** Ministry of Science, ICT and Future Planning in Korea, "Study on near-earth space environment changes"
   Amount: $300,000 at 2015
   Date: January 1st, 2015

3. **Title:** Ministry of Science, ICT and Future Planning in Korea, "Study on effects of CMEs and high-speed solar wind on near-earth space"
   Amount: $450,000 at 2014
   Date: January 1st, 2014

Attachments: Publications a) listed above are attached.